PART ONE

FROM THE STRATOSPHERE TO THE SEA-BED

1: *In the Stratosphere*

THE technical means called upon for the exploration of the high atmosphere and the submarine depths present such striking analogies that my editor has asked me briefly to review the conquest of the stratosphere.[1] This work essentially aims at the description of my bathyscaphe and its voyages. Why did the achievement of the *FNRS*, for such was the name of my stratospheric balloon, precede that of the bathyscaphe? This is what I want to explain.

From the beginning of the last century it had been noticed that gases reputed to be perfect insulators for electricity could in reality, in certain conditions, conduct it. It had been observed, in particular, that the passage of electricity through the gases was possible when these gases were exposed to the radiation of radio-active bodies. But, what was surprising, these observations made in a balloon, for the atmosphere at altitudes of $2\frac{1}{2}$ miles to $5\frac{3}{5}$ miles,[2] revealed an increase of conductivity, while, as the distance from the earth and its radio-active bodies increased, it had been expected that a decrease would be observed. This led physicists to adduce the existence of another phenomenon, that of cosmic rays coming from outer space.

It was to enlarge our knowledge in this domain that I, a physicist, conceived the idea of ascending into the stratosphere.

Let us recall in a few lines what this word signifies. The higher we rise in our atmosphere, the lower are the temperatures we encounter. But, as Teisserenc de Bort discovered by means of his sounding-balloons, between $3\frac{3}{4}$ miles and 10 miles, according to the latitude and the season, we encounter a very marked limit beyond which the temperature ceases to fall, or even increases slightly, with the altitude. Here, from the meteorological point of view, begins the stratosphere, the region where the vertical displacements of air, which produce the

[1] On this subject see my book: 'Above the Clouds' (*Au-dessus des nuages*); Bernard Grasset, ed.

[2] These and all following calculations are suitable approximations to the figures in Professor Piccard's book. (Translator.)

condensation of water and the formation of the clouds, no longer exist. Thus the stratosphere is rightly termed the region of perpetual good weather. It is because it commences at $7\frac{1}{2}$ miles, as an average in our regions, that aviators in their everyday usage give this altitude as its lower limit.

It was to this high region, to be more precise to an altitude of 10 miles, that I wished to ascend to meet the cosmic rays in order to observe them in mass, where their initial properties would not yet have been too modified by collisions with the molecules of our atmosphere.

For a number of investigations, use had been made of sounding-balloons, the classic free balloon scarcely allowing man to do useful work beyond $3\frac{3}{4}$ to $7\frac{3}{8}$ miles. Beyond this range, in fact, the air is too rarefied for our organism, and even if the aeronauts have an equipment permitting them to breathe pure oxygen, they cannot stay for long above about $7\frac{1}{2}$ miles. The sounding-balloon was thus, for meteorologists, the sole means of exploring the high atmosphere. A generation had laboured to devise automatic instruments for recording pressure, temperature and humidity. But the measurement of cosmic rays was a delicate operation very different in nature, and could not be effected at the time with the necessary precision by these automatic instruments. That is why I decided to ascend myself to 10 miles. Luckily I was licensed as a free-balloon pilot and I had already made a dozen ascents. May I here relate how I became an aeronaut?

Like most young men of my time, I had a passion for everything related closely or remotely to this new science. It was the epoch when the heavier-than-air machine was making its first essays and when only optimists foresaw the future development of aviation: the lighter-than-air machine was still king of the sky. As a young physicist I naturally read all the aeronautical journals within reach. A question was being discussed in them by specialists: that of the distribution of the gas temperatures in the interior of spherical balloons. Now, I did not agree with the published results. These seemed to me to be in contradiction with theory, and this was explained by the fact that the method of measurement chosen was not suitable. It was necessary to take the measurements again in better conditions. I addressed myself to the Swiss Aero-Club (Aéro-Club Suisse) which, understanding the importance of the problem, permitted me to make several ascents with

this scientific object. These were my first trips. I had in the interior of the balloon, along its vertical axis and also in the neighbourhood of its equator, a dozen electric thermometers, thermo-couples whose cold junctions were in the basket of the balloon. I myself constructed a simple and exact potentiometer and by means of an Einthoven galvanometer I could measure the temperatures of the gas within approximately a tenth of a degree. At the same time I could, by means of a rubber tube, take samples of gas from different parts of the balloon when it was at different heights and from them determine the density by means of a bunsen apparatus. This permitted me to follow the diffusion of the air coming in through the neck and being slowly mixed with the gas. All these measurements were made for daytime and for night-time at different altitudes, so as to show more clearly the influence of solar radiation.

These studies familiarized me with the balloon. I did not then think that later they would lead me into the stratosphere.

I have said that it was the study of cosmic rays which had led me into the stratosphere. As a matter of fact I had also another reason for going up there myself: I wanted to induce the air services to use the high atmosphere, to travel at high speeds at an altitude where the rarefied air offers less resistance. But since, in the stratosphere, the low pressures make human life impossible, I was going to have to make use of an airtight cabin permitting the maintenance of an almost normal atmosphere. The specialists of those days considered my suggestion as unrealizable. What today appears elementary to us, in those days seemed Utopian. But the single objection that they were able to make to me was that up till then no one had ever done it. How often have I heard reasoning of this sort! But it is just the function of the engineer to place his reliance upon theory when creating something new. If I had been an aviator I should perhaps have constructed, at the beginning, a stratospheric aeroplane. But being an aeronaut I plunged into the construction of a balloon. It was besides a relatively simple thing to suspend an airtight cabin to the free balloon.

The Belgian National Fund for Scientific Research (*Fonds National Belge de la Recherche Scientifique*), which had just been founded by King Albert I, supported my project and accorded me the necessary credits. In homage to the *Fonds National* the balloon was baptized the *FNRS*.

I wanted to ascend, as I have said, to meet the cosmic rays at a point where they would not yet have traversed more than a tenth of the

atmospheric mass. Now at such an altitude the pressure is, naturally, no more than one-tenth of an atmosphere. In other words, at this height the pressure of the air is no more than a tenth of that we experience at sea-level. As the lifting force of a balloon is proportional to the density of the air displaced, as Archimedes would have already told us, I had thus to construct a particularly large and light balloon, so that it could carry observers, instruments and the airtight cabin.

I spare the reader the calculations I made: I had to have an envelope of 223,560 cu. ft., of 114 ft. in diameter, made of a material of the least possible weight. Here arises the principal difficulty in the construction of stratospheric balloons: a balloon of this volume, completely inflated with hydrogen, would have, at its take-off, a static lift of nearly 16 tons. To resist this force, material and net would have to be extraordinarily strong, and thus heavy—so heavy that the balloon would never reach 10 miles, where a cubic yard of hydrogen supports only one-tenth as much as it does down here. To permit the use of a light envelope, then, it was necessary to introduce into our balloon, at the moment of take-off, only a small part of the gas that it could contain, one-fifth of its maximum volume. During the ascent this gas would expand under the effect of the decrease of atmospheric pressure and only in the stratosphere would the envelope take its spherical form.

Which of my readers has been present at the rigging of a spherical balloon? The envelope is spread out on the ground, like a cast-net. Upon it the net is disposed. The gas is introduced. The envelope dilates and lifts up the net, which is held (and stretched) by bags of ballast. As the volume of the envelope increases, the bags are taken from mesh to mesh to be hooked on lower down. During this whole operation care must be taken that the folds in the expanding envelope open out completely, without being caught in the folds of the net. When the envelope has become spherical and has attained the desired height, the ropes attached to the net are affixed to the hoop and the balloon is prepared for the ascent. All this is accepted practice.

But our *FNRS* was to receive, at the beginning, only a small part of the gas which would later inflate it entirely. It was thus only the upper portion which would contain gas, the rest of the envelope remaining empty and hanging in great loose folds which would be progressively filled during the ascent. In these circumstances what was to be done to avoid the accidents arising from folds partially retained in the net? We could not count upon a procession of guardian angels

to release the folds during the ascent; and as we could not give up the envelope, we were obliged instead to give up the net. It was therefore necessary to suspend the car directly to the envelope by means of a belt. (Fig. 1, Plates 1 and 2.) Here arose a difficulty of

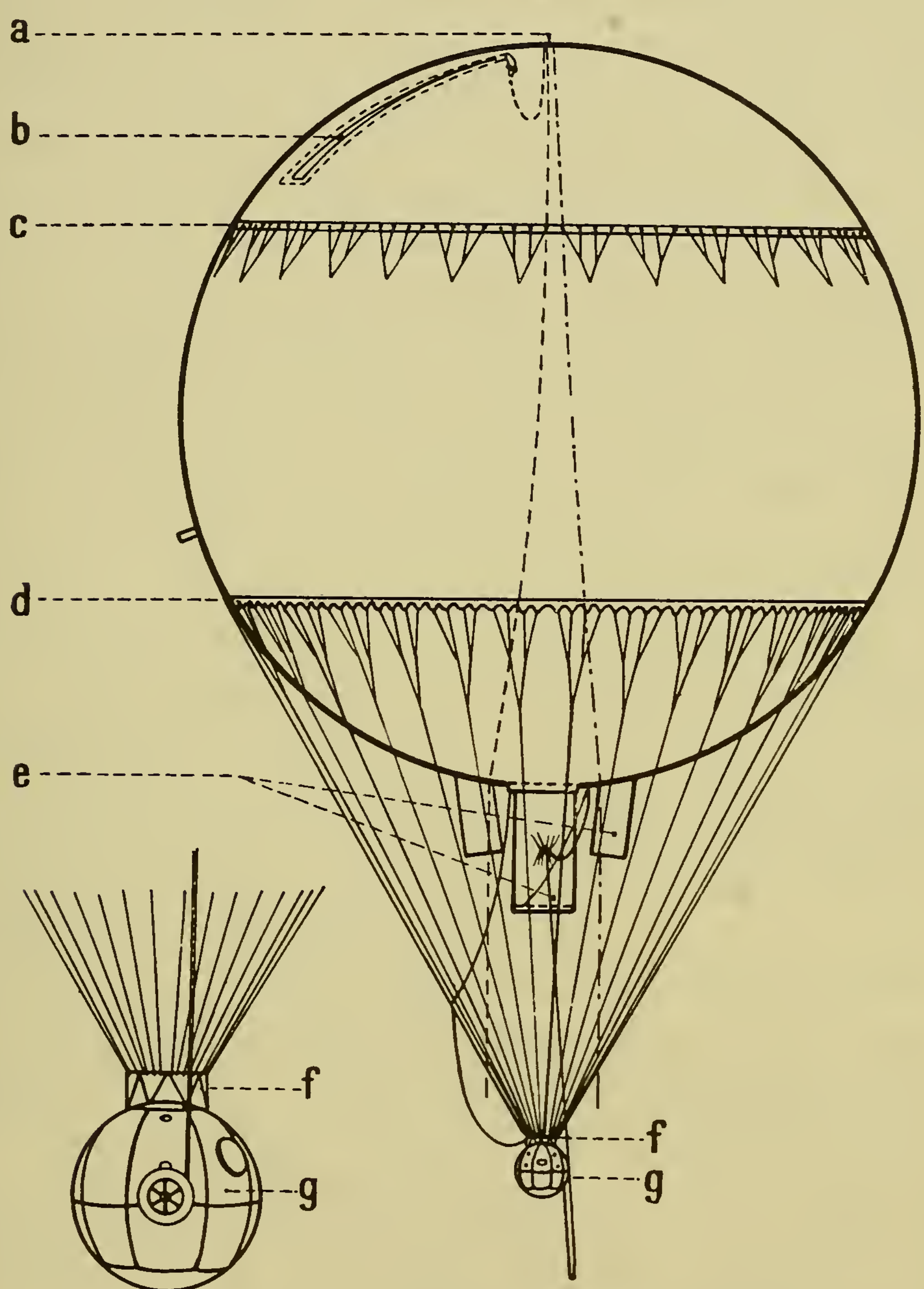

FIG. 1. The stratospheric balloon *FNRS*

a. Valve
b. Ripping panel
c. Ground-manœuvring band
d. Load-bearing band
e. Necks
f. Attachment of cabin to the envelope
g. Car

a new order. I had chosen Augsburg as the point of departure because it was there that the balloon had been constructed by Riedinger. Augsburg besides had the advantage of being distant from the sea

in any direction. But a balloon, as well as a car, is subject to severe regulations. It must be constructed according to classic norms to obtain its certificate of airworthiness. Now my balloon varied from them in an intolerable manner, as much by the absence of a net as by the extreme lightness of the construction materials ($2\frac{3}{5}$ oz. to a square yard for the upper three quarters and only $1\frac{3}{5}$ oz. for the lower quarter, the whole covered by $2\frac{4}{5}$ oz. of rubber to the square yard).

An administration can make no exceptions, above all when a foreign professor is in question! The German permit was thus refused to me. Fortunately the international agreements allow a Swiss aeronaut to leave Germany with a Swiss certificate of airworthiness originating in Berne, and Berne, more liberal, gave me the authorization asked for.

Let us now look at the basket of our balloon, or rather at what it had instead of a basket. We must have a hermetically sealed cabin, carrying breathable air at ordinary pressure, and able to resist this internal pressure even when the outside pressure will be no more than one-tenth of an atmosphere. Our lives depend upon the airtightness and the strength of this cabin. Let us, then, have a spherical cabin in sheet aluminium of one-seventh of an inch (3·5 mm.) thick. The diameter will be 7 ft. (210 cm.). Two observers, surrounded by their instruments, will be perfectly comfortable here, surveying the outside world through eight round portholes of a convenient diameter, that of 3·15 in. (8 cm.). To avoid the danger of breakage caused by the difference between the pressures prevailing on the two faces, these windows are constructed of two sheets of glass, each 0·3 in. thick, separated by a thin layer of air which contributes to thermal insulation. We thus prevent the formation of rime on the windows, even in the stratosphere, where the external temperature is in the neighbourhood of $-76°$ F. These windows offer no danger of breakage even when obliged to sustain a difference in pressures of nine-tenths of an atmosphere.

I did not imagine then that, nine years later, I should construct portholes to resist a pressure of 600 atmospheres.

How could we, from this sealed cabin, manage to drop ballast without air escaping? The principle of the air or water lock is well known. Here is how, when I was still a child, I observed its functioning for the first time. One day I was taken to visit a menagerie. In one of the cages was a lion and a lion-tamer. How would the tamer get out without the lion being able to follow him? It was a revelation for the little lad that I then was: the tamer went into a little adjoining cage through

a door which he closed behind him: only after this did he open a second door which gave him access to the outside: at no time were the two doors open at once and the beast had not been able to get out. Forty years later I had not forgotten this scene. The tamer was now the ballast, which had to get out of the cabin without allowing the lion, that is, the air, to follow it.

It was sufficient to apply the principle of the air-chamber: let there be a container provided with two straight-through taps. By means of a funnel, we pour the ballast into the container through the upper cock, the ballast being composed, in our case, of lead-shot. Then, after this cock is closed, the lower cock is opened and through it the ballast pours directly towards the outside. So that the lead-shot in falling might not injure spectators, a very fine shot is needed. I made sure myself that there was no danger, by standing at the bottom of the big chimney of the University of Brussels under a rain of shot which was poured on my head from a height of 165 ft.

All would have been for the best if international regulations had permitted anything other than sand or water for ballast. What was to be done? To cut all discussion short, I declared that I had as ballast lead-sand. This explanation aroused no objection. However, by definition, sand is a non-metallic substance and nobody has ever seen lead-sand! I thus imitated the famous priest in the anecdote who was served with roast chicken on a Friday: he baptized it 'carp' and was thus able to enjoy it with a quiet conscience.

Let us note in passing that it was iron-shot which was used as ballast for the three bathyscaphes.

My brother, for his balloon, has found a graceful method of resolving the problem and satisfying the regulations in force: this time the ballast is of sand, real sand, and the sacks which contain it are arranged on the outside of the cabin: each one of them contains a detonator which electric conductors connect with a battery lodged in the cabin. A simple pressure on the switch button suffices: the sack rips open and empties itself. Afterwards this arrangement was adopted on the *Explorer II*, with which the American pilots reached $13\frac{2}{3}$ miles. The balloon had been inflated in a sheltered valley: the balloon commenced its ascent when, suddenly, the wind beat it down upon trees standing on a ridge. If the pilot had not immediately made use of his switchboard the *Explorer II* would have been destroyed. No other system of unballasting would have been speedy enough to save the balloon.

I cannot here give the whole story of the construction. However, I should like to describe one incident. It happened at the moment when the building of the car was nearly finished. The cabin possessed two manholes, closed by means of hatches to be put into place from inside: the pressure prevailing in the cabin forces the hatches against the joints. This principle is employed in all pressure chambers: the hatch naturally has a diameter greater than that of the opening. However, in order to be able to introduce the manhole cover usually the manhole is made oval: the cover is inserted by first putting in the small end and then by rotating it, bringing it into place. On the contrary, I had asked that the manholes in my cabin should be circular: for one thing, this system guaranteed better airtightness, and for another, the round shape better suited the spherical form of the cabin. In such a case, when the cabin is finished, there is no longer any possibility of getting in the hatches. I had therefore remarked that the covers should be placed in the cabin before they welded the last sheet of aluminium. When giving the order I had once more insisted upon it: of course, the directors of the factory were of my opinion, but not the worker responsible. Better than anyone else, he knew how to manage it: it was not the first pressure chamber that he had built and he had always seen the manhole cover put in last of all. (I even suspect him of never having understood why the manholes were oval.) For him, a man of action, only practical experience counted. He was wary of theory and was not going to let anyone impose upon him: still less a university professor whose reasonings were abstract. The car was welded then, but—without hatches.

I was invited to examine the finished effect. My first glance went to the inside of the cabin.

'But you've forgotten the hatches!'

'No, they're there.' And I was shown the hatches nearby.

'But you know that they should be inside. Now you won't be able to get them in.'

'But I don't see why not,' he replied, convinced that his experience was as good as that of ten university professors.

He took up a hatch and turned it about in every direction, like a child trying to push a saucepan lid into the saucepan. Then, when I returned to the factory, the two covers were inside the cabin. I paid tribute to the dexterity of the workers: and I am still wondering whether they had cut open the walls again or if they had cut through

the hatches and rewelded them once they were inside. The repairs were, in any case, completely invisible.

Augsburg, September 1930. On the 14th September the balloon was inflated. Knowing that the wind would hinder the rigging of this large balloon and could even render departure impossible, we had waited several weeks for favourable weather forecasts. But to our great despair the weather changed abruptly, a violent wind took a hand and we had to empty the balloon and give up the idea of departure. A great disappointment, it goes without saying, for the public and the Press!

We waited once more for a more clement sky, but in vain. We had to wait until spring, winter not being a season favourable to an experiment of this sort. Finally, on the 26th May 1931, the weather forecasts were favourable. In the night of the 26th–27th May we got the balloon inflated: 100,000 cu. ft. of hydrogen. But on the morning of the 27th the wind rose once more and knocked the balloon about: the cabin was thrown out of the transporter and put slightly out of shape (later we were to notice the consequences of this). However, with my friend and collaborator, Paul Kipfer, I went into the cabin and we closed the manhole behind us. The wind increased. To hold the balloon, they attached, without my knowledge, a supplementary rope to the hoop. At 3·57 p.m. Kipfer, looking out of one of the portholes, said to me:

'A factory chimney is passing underneath us!'

They had let the balloon go and forgotten to give us the signal of departure that had been agreed upon!

We went up very quickly. Some moments afterwards I perceived that the insulator of an electric sounder going through the wall of the cabin was broken at the time it fell: the air—our precious air—was rushing out, whistling through the hole. Fortunately I had had prepared a mixture of tow and vaseline, expecting that this paste would be useful in case of a leak. I surrounded the insulator with insulating tape and with this paste. The work was not easy.

Soon Kipfer, who was observing the pressure gauges, said to me:

'We are at $2\frac{1}{2}$ miles and there is still an equal pressure inside and outside the cabin!'

Well, why have I had this beautiful aluminium cabin built? Since it leaks like a basket, a simple wickerwork car would have been as serviceable! The situation was critical. I said to my companion:

'If we don't become airtight immediately, we must pull the valve and land, if we don't want to suffocate.' We didn't yet know that the rope of the valve was blocked. . . .

Both of us confident in this last resource, I went on with my work. But the hole was big! Bit by bit, however, the whistling grew feebler, then was silent. Never have I appreciated silence so much. The pressure already in our little home had gone down to less than two-thirds of normal. Happily we had a reserve of liquid oxygen. I poured some of it on the floor in small quantities[1] and the oxygen rapidly evaporating increased the pressure.

We still went up. The sky became darker.

Twenty-five past four! Twenty-eight minutes ago we were still in Augsburg, 1650 feet above sea-level.

'What altitude, Kipfer?'

'51,200 feet.'

In less than half an hour we had gone up over 9 miles. The balloon, whose shape at the moment of departure was rather that of a dried pear than of an apple, had now inflated following upon the expansion of the gas and had become perfectly spherical. The excess gas escaped by the neck and our aerostat reached its first position of equilibrium.

At last here we are in the stratosphere!

Around us the sky. The beauty of this sky is the most poignant thing we have seen: it is sombre, dark blue or violet, almost black. If the air were perfectly transparent, we should see the earth over a radius of 280 miles, and our visual field would cover 246,000 square miles of the planet (more than the surface of all France). But beneath the stratosphere there is the troposphere, whose upper limit on that day was about $7\frac{1}{2}$ miles: it is much less transparent. At the horizon we perceive the confines of the two zones, as if drawn with a ruler. If one looks obliquely across the troposphere, the earth, so distant, is invisible: there is nothing to be seen but fog. But the more the glance is directed downwards, the more visible is the earth. Beneath us is the Bavarian plain. But, even if we look vertically down, the picture is blurred as in a bad photograph. There is, in fact, between us and the earth nine-tenths of the atmosphere, almost as much as if, at sea-level, we were looking at the moon. Alone, the mountains emerge from the foggiest regions of the troposphere. At first hidden by clouds, they

[1] If one pours out too much oxygen at a time, the sudden increase of pressure affects the ear.

reveal themselves bit by bit: a summit, then another: at last, all the snowy chains of the Bavarian Alps and the Tyrol, which we are approaching gradually.

In spite of the splendour of the spectacle, we took precautions. We threw out over a hundred pounds of ballast, which caused us to rise some hundreds of yards.

We soon made a very unpleasant discovery: the rope which controlled the valve was not working. It was tangled with the supplementary rope which was affixed at the moment of departure. Now, if we could not open the valve, we could not let the gas escape, to begin the descent. Instead of obeying us, the balloon would go down only when external conditions permitted it, that is to say, when it grew colder at sunset. Where should we be then? Over the land? Or above the Adriatic?

As it descended, the balloon would grow longer: the rope operating the stopped-up valve would therefore be stretched out, and would open the valve, accelerating our descent more than we wished.

However, to carry out our programme and reach that altitude where the pressure is only one-tenth of an atmosphere, we threw out more ballast and soon we saw a difference on our barometer between the two meniscuses of 2·992 in. exactly. Being used to seeing in the laboratory, on our barometers, columns of mercury of 29·92 in. we had a curious sensation when we read a barometric height reduced to one-tenth of what we call its normal value.

We should have been perfectly happy if it had not been for this incident of the valve. The future was uncertain. What were we to do? We decided not to throw out any more ballast, partly to shorten our trip, and partly, also, to be able to dispose of what remained at the moment of landing. Then we decided to pack up the instruments. If the balloon, as it drew out in length, itself pulled open the valve and thus occasioned too sudden a landing, we had to take precautions against being injured by loose objects.

We tried once more to open the valve by turning the windlass winch around which the cable was wound, by means of a crank placed inside the cabin. But the cable broke clean off, which definitely put at an end any hope of controlling the balloon.

There we were, prisoners of the stratosphere. Fortunately we had at our disposal a good reserve of oxygen, and of alkali, which is used to absorb the carbon dioxide produced by our breathing. Although

our programme provided for a landing about midday, I had a reserve which should have let us remain shut up in our cabin until sunset. Provided, at least, that we could keep the cabin airtight. Having felt several times, in our ears, a sudden lowering of pressure, we perceived that we were once more losing air through the hole near the insulator; the vaseline had run out through the tow. So the struggle for life began again. The longer the trip took, the greater was the danger of reaching the Adriatic. We had a drift indicator which hung 50 yards below the car. As long as land was visible, it permitted us to determine our speed and the direction of our drift. The direction was, in fact, towards the Adriatic. Our speed was, luckily, very low: if it did not increase we were sure not to leave terra firma during the day. In the stratosphere the wind is often very violent. On certain days it would have borne us as far as above the Persian Gulf. If I had known the mountains which surrounded us, I could have found our position. But the view was too often obstructed by clouds to permit us to follow our course on a map. It would not have helped us much anyway. We could do nothing about it and all we could do was to await the turn of events.

As a last stroke of ill-luck, one of the large mercury barometers broke as the result of an awkward movement. The liquid metal flowed to the bottom of the cabin. Now, in certain cases, aluminium can be rapidly eaten away by mercury. Fortunately a good layer of paint protected the cabin. Nevertheless the presence of mercury was not reassuring. If only we had possessed a little pump with which we could have sucked it up! We had with us a rubber tube. If only, we thought, we had had a vacuum cleaner! As a matter of fact, never had a physicist at his disposal more vacuum than we had! The whole stratosphere was at our disposal. We connected our tube with a tap which led outside and we placed the other end on the cabin floor. The mercury was sucked up and thrown outside as well as the condensed water which had accumulated at the bottom of the sphere. But we hadn't come to the end of our difficulties.

We had departed before sunrise and we had traversed at high speed those zones where the temperature was between 50° and 75° C. below zero. The walls of the cabin were then very cold and its interior was rapidly covered by a good layer of frost. It was as if we were in a drop of crystal. If the situation had lasted, we should have suffered seriously from the cold. But soon the sun rose, the stratospheric sun.

Its radiance is twice as intense as at sea-level. The aluminium became heated and the frost dropped off. It began to snow in our cabin.

Bit by bit the temperature rose. 70° F. was very pleasant. 85° was bearable. But over 100° was too much! We sat down as low as possible in the sphere, as there it was coolest, but still we got very thirsty. I had asked that two big bottles of water should be put in our cabin: we found only one small one. Beneath the flooring with which the rounded bottom of our cabin was covered, the condensed water had collected: there would have been enough of it, but dust, oil and mercury made it into an undrinkable emulsion. Luckily Kipfer discovered a spring: fresh water, clean and distilled, flowed along the wall, on the shady side: there was not much of it, but it sufficed to wet our tongues from time to time. I found something even better: when we poured liquid oxygen into an aluminium goblet and waited for the oxygen to evaporate a thick layer of frost was formed outside. But it was so cold it burnt to the touch, for it was formed at −350° F.: we had to wait a bit until its temperature was that of melting ice.

12.30 p.m., the sun at its zenith. At last the entire cabin came into the shadow of the balloon; and the temperature sank. One side of the cabin was painted black, the other being left bright. I had intended, by making the balloon turn round, to regulate the temperature, since black absorbs more heat than a bright metal: but the motor intended to bring about this rotation had been damaged at the time of departure: the whole morning it was the black side which had been exposed to the sun. During the afternoon the balloon turned round: and so we no longer had to suffer from the heat.

Towards two o'clock in the afternoon we began to descend very slightly. But a rapid calculation showed us that at this rate we should take fifteen days to get down! As a precaution, we decreased the outlet from our oxygen apparatus and we kept as still as possible so as not to turn too great a quantity of this precious gas into carbon dioxide.

3 p.m. The speed of descent is more marked. However, it would still take twenty-four hours at this rate to land. All the same the descent is getting faster: that is the essential thing.

4 p.m. 5 p.m. 6 p.m.! The hours are passing. We are crossing the Bavarian Alps. The sun is going down. The balloon, now colder, descends faster and faster.

8 p.m. Altitude 7½ miles. At last we had left the stratosphere. By the fog which suddenly covered the distant horizon we saw that we

were passing into the troposphere. Below us twilight flowed through the valley of the River Inn. On the ground, we found out later, people saw an unusual sight. The balloon, still in the sun's rays, appeared to the earth-people brilliantly illuminated against the dark sky. Until today, only the planets and the moon have been seen lighted up in this fashion. So they took us for another heavenly body. To the observers nearest at hand, the illuminated part of the balloon appeared in the form of a crescent. Had a little moon been born? Nothing was missing, it even had a halo. This was produced by the light reflected by the balloon and diffused in the fogs of the already obscured troposphere. (On the 18th August 1932 the reverse took place: our friends who were following us in a car were speeding in the direction of Venus, which they took for our balloon.)

The sun disappeared beneath the horizon. We descended more and more rapidly. Now it is known that if more ballast is thrown overboard than is necessary to stabilize a descending balloon, and the valve is not opened, the balloon will generally climb again to its earlier position of equilibrium. We had to be very careful then, when throwing out ballast, not to go back at one jump to 10 miles up. It was just unfortunate if the landing proved a little rough.

By means of the tap which communicated with the open air, we slowly decreased the pressure in the cabin, so that we could open our manholes as soon as possible.

Kipfer watched the barometers. At 15,000 ft. he announced equal pressures within and without. We opened the manholes immediately and put out our heads. After having been shut up seventeen hours, we were at last in the open air. Above us, the starry sky. Beneath, the high mountains, snow and rocks. The moonlight was magnificent. Two little clouds were lighted up from second to second by stormy discharges: but we saw no lightning nor heard any thunder. To be ready for anything, we prepared our parachutes, but the balloon very luckily left the stormy zone.

A glance towards the horizon: it still formed a straight line. But soon gloomy silhouettes emerged: mountains. We were already lower then than the highest peaks. Things were going to happen fast. We were in the high mountains near a pass covered with ice. On the south side it appeared to lead rapidly down towards the plain, but we were drifting northwards. Because of the danger of climbing again to 10 miles with the manholes open, we dared not cast out any ballast, and

were obliged to manœuvre only by means of the ripping panel. We touched a very steep field of snow. In my hand I held the strap which allowed me to open the panel and to empty the balloon almost instantly. But I took good care not to do it: the site was not suitable for a landing. The balloon bounced and flew over a glacier. It was a maze of crevasses. One moment I could see the lights of a village, and I flashed a signal towards it with a torch. (The next day we learnt that this signal was seen perfectly from Gurgl.) But the village disappeared in the valley. At last we approached a flat place free of crevasses. Now was the moment! Kipfer pulled the strap of the ripping panel; the balloon quickly emptied; we touched the ice, the cabin rolled a little, then came to rest.

My manhole was on top, so I had an unrestricted view. The envelope was floating above us. The wind was so light that at every moment it threatened to fall on the cabin: then it leant over and lay down on the glacier: the opened ripping panel being underneath, it emptied only very slowly. A glance into the dark cabin showed me a heap of strange objects: 400 lb. of instruments, 750 bags of small shot, all scattered about upside down. And underneath, Kipfer, who was slowly picking his way out towards the top.

We had landed at an altitude of some 8700 ft. Switzerland? Austria? Italy? We bivouacked where we were. The place would have been fairyland if it had not been so cold! Wrapped up in the balloon material, I went to sleep, but I started from sleep from time to time, woken by the noise of a waterfall which in my dream I mistook for the whistling of our air leak! At dawn, from aeronauts we became alpinists: linked by a double rope, sounding the snow at every step with a bamboo stick found in the rigging of the balloon, we reached the edge of the glacier, and seeking out passages across the rocks, we went down slowly towards the valley. At midday a patrol of skiers came from Gurgl to our rescue, reached us and led us to the village. It is with gratitude that I think of the valuable help given to us as much by the mountaineers as by the authorities in the Tyrol. Forty men, twenty soldiers and twenty peasants carried the envelope of the *FNRS* on their shoulders from the Gurgl glacier to the village, without a path or on the worst trails and all this without one tear in the delicate material.

A few days later, at Zurich, where the Swiss Aero-Club welcomed us in triumph, its president, Colonel Messner, congratulated us, and expressed the hope that the world altitude record which we had just

set up would not be beaten for many years. In my reply I had to contradict him.

'It will be a fine day for me,' I said, 'when other stratospheric balloons follow me and reach altitudes greater than mine. My aim is not to beat and above all not to maintain records, but to open a new domain to scientific research and to aerial navigation.'

In the months that followed, although we reached the altitude we aimed at, our enterprise was called foolhardy, partly because the valve rope became jammed: if we are safe and sound, it appears, it is a miracle. My spherical balloon had a bad press: I had no emulator, at least at the beginning. Meanwhile I kept myself occupied with work on cosmic rays. After a while I wanted to make a new ascent. This time it was my friends of the Aero-Club of Zurich and more especially Dr. E. Tilgenkamp, Colonel Garber and Dr. Bonomo who took it upon themselves to organize it.

In the early days of August, the weather forecast seeming favourable we decided to set forth the next day: the balloon was to be inflated during the night. In the afternoon, in radiant weather, the envelope arrived and was spread out. A little later, M. Jaumotte, director of the Belgian Meteorological Institute, rang me up from Brussels. He had heard that we were planning to take the air, but he warned me that thunderstorms were expected over central Europe during the night. Zurich confirmed this forecast, so I did not hesitate. Although the crew was already mobilized and everything ready for the business of filling the balloon, we cancelled the departure.

I still remember what the reporters thought of it: for was not the sky cloudless? Fortunately I stuck to my decision. And I smiled when later a violent storm burst over Zurich and Dubendorf. That night, I am sure, meteorology gained prestige in the eyes of the international press.

On the 17th August, finally, the forecast was good. In splendid weather, in the night, without a breath of wind, the *FNRS* was inflated: on the 18th, before sunrise, all was trim and at seven minutes past five in the morning, 'Let go!' rang out. What can I say about the ascent? Everything went smoothly according to our plan, like a laboratory experiment prepared with minute care. We found out that the particular gamma radiation, which according to a certain hypothesis should have been manifest above in an intense fashion, did not exist. Enjoying perfect visibility, we drifted slowly above the Lake

of Wallenstadt, the Grisons, then the Lago di Garda, in the direction of Desenzano, where we arrived at 5 p.m.

Every landing in a free balloon has its surprises. It is one of the charms of the sport. At the moment when the guide-rope was about to touch the earth, I collected my best Italian to hail a crowd which gathered:

'*Prego, tenere la corda!*' (Please take the rope.)

And the answer, in German-Swiss:

'*Jo, Herr Professor, mir häbets dä scho.*' (Yes, Professor, we have it.)

It was my compatriot Zweifel, the engineer from Glaris. With his help, we made a perfect landing.

The geodetic surveyors of the Swiss topographic service, using the theodolite, calculated the greatest height attained to be 55,800 feet with a 'probable' margin of error of about ten feet. Calculated on the barograph, according to the rules established by the *Fédération aéronautique internationale pour l'homologation du record mondial* (International Aeronautical Federation for the Verification of World Records), it was no more than 53,400 ft: the difference—2400 ft.—is explained by the fact that the regulation takes account only of mean pressures at given heights, while the real pressures vary from day to day on account of meteorological conditions. We thus beat our preceding record, that of the 27th May 1931: Colonel Messner was satisfied: it stayed with Switzerland. As for me, I was satisfied too: this time we were able to bring our scientific programme to a satisfactory conclusion.

This ascent of the 18th August 1932 broke the ice: the airtight cabin acquired full civic rights in ballooning and aviation.

Work was begun on several stratospheric balloons: three in the United States, two in Russia, one in Poland, all larger than mine. Not for a second did I regret that the *Century of Progress* carried off the world record for the United States. No more than I regret that the French Navy, breaking my record of 3150 metres, dived to 13,287 ft. (4050 metres), off Dakar, with the *FNRS 3*, a bathyscaphe in the construction of which I took part.

What happened to the *FNRS* after that? Two years later, to the very day, on 18th August 1934, having on board M. Cosyns, pilot, and M. van der Elst as assistant, it rose once more into the stratosphere, to establish the connection between the Ardennes and the mountains of Jugo-Slavia. For other ascents money was lacking. When, because

of age, the rubberized envelope began to split and the balloon was unusable as a gas aerostat, Cosyns and I tried to make a Montgolfier (hot-air balloon) out of it. The attempt was not devoid of interest: moving with the air, the spherical balloon would have escaped the cooling action of the wind, and the heat of the sun would have warmed it sufficiently to keep it in equilibrium without auxiliary heating. However, the neck was too small for a hot-air balloon: driven back by a sudden wind before the take-off, the envelope took fire and was destroyed in a few seconds by the flames.

The advent of electronic instruments might have sounded the knell of the era of the stratospheric balloon: in fact, equipped with automatic instruments, sounding-balloons today allow us to make meteorological and physical observations in better conditions and at less cost.

But the aerostat still has a task to fulfil: that of observing the spectrum of solar light reflected by the planets. If we can attain this, we shall know the composition of the atmosphere which surrounds these celestial bodies. We shall know then if there is oxygen in the atmosphere of the planet Mars, hence if, from this point of view, life is possible there. For that, a spectrograph must be directed upon Mars: but no mechanical device as yet allows us to direct a telescope automatically upon a heavenly body: the presence of an observer is indispensable. So that terrestrial oxygen may not falsify observations the astrophysicist should not have above him more than one-hundredth of the terrestrial atmospheric layer: or in other words, he should rise to over $18\frac{1}{2}$ miles. At that height the lifting force of a metric cube of hydrogen (33·9 cu. ft.) is reduced to 10 grams ($\frac{3}{7}$ ounce): the balloon would have to be, at once, extra-light and of large volume. My brother's *Pléiade*, with its hundred rubber ballonets which support the cabin, would seem to be of particular interest: during a preliminary trial it attained the altitude aimed at of 9900 ft.

Nevertheless, to reach over $18\frac{1}{2}$ miles of altitude it would be necessary to increase the volume and the number of ballonets of the *Pléiade* and, naturally, make use of an airtight cabin. The cost of such an experiment would rise in proportion: for the moment it cannot be attempted, money lacking: it is a pity. My friend Audouin Dollfus, astronomer and aeronaut, is making efforts at the present time towards this end. I hope he will bring them to a satisfactory conclusion.

After having journeyed through the stratosphere, let us now penetrate the oceanic deeps.

Plate I The *FNRS* takes off for its ascent to 10 miles, 18th August 1932

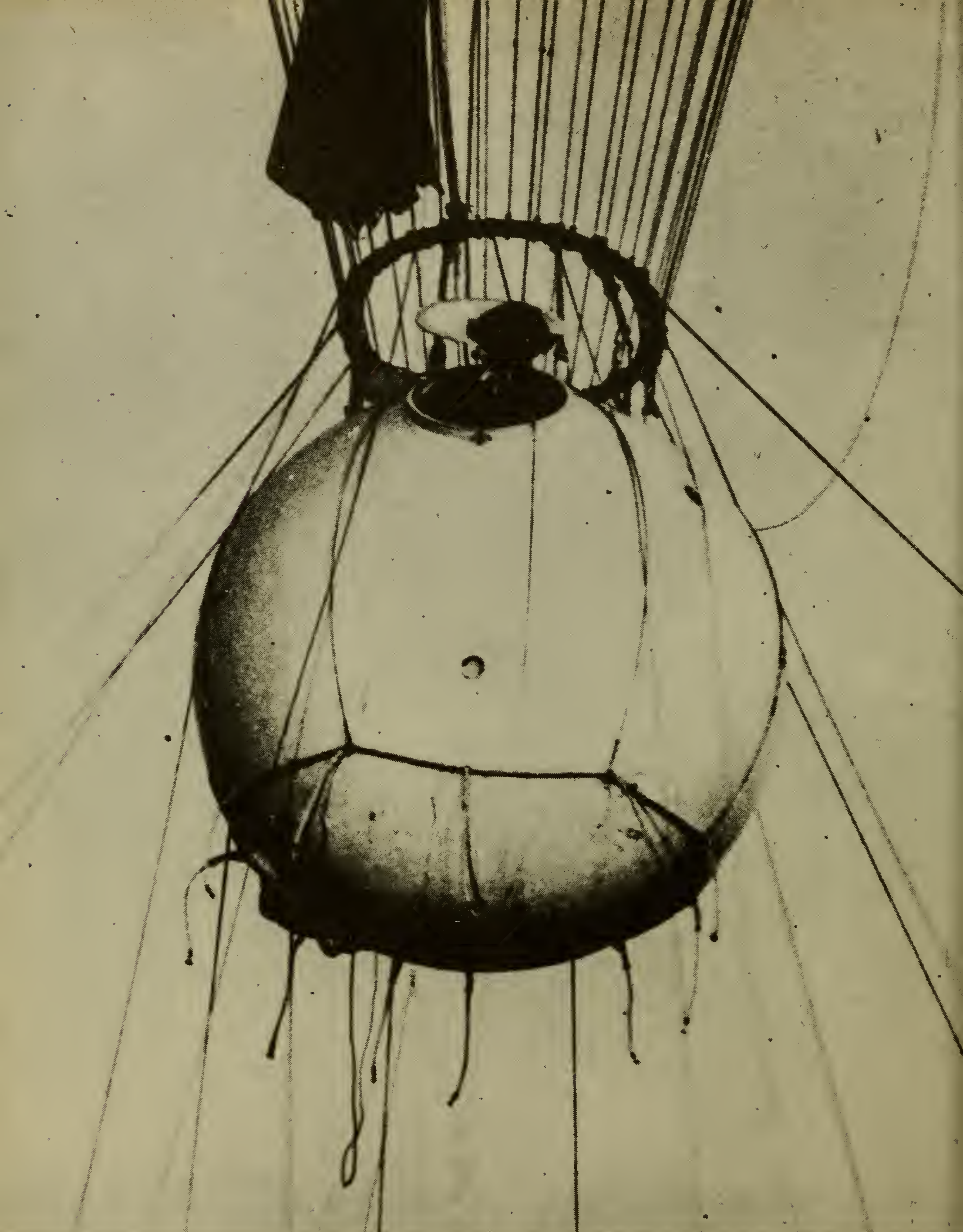

Plate II The cabin of the *FNRS*, with Professor Piccard at the manhole. The emergency parachute can be seen top left